APPENDIX 7.7. GAS AND ELECTRICITY USE FOR MODULATING FURNACES

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APPENDIX 7.7. GAS AND ELECTRICITY USE FOR MODULATING FURNACES

7.7.1 INTRODUCTION

The Department modeled two-stage modulating furnaces with both high and reduced firing rates. The two different firing rates change the amount of gas and electricity consumed by the furnace burner and circulating air blower motor. This appendix describes how DOE calculated the gas consumed by the burner and electricity consumed by the circulating air blower motor at the two firing rates. This calculation method is based on the procedure in the ASHRAE Standard 103.[1]

The gas consumed by the burner during the two firing rates depends on the amount of time the burner is firing at each mode and the gas consumption rates. The first section of this appendix discusses the calculation for burner operating hours and firing rates. The six variables for the burner operating hours calculation are: fraction of heating load, balance-point temperature, oversize factor, heating capacity at high rate, heating capacity at reduced rate, and the design heating requirement. The second section describes the circulating blower motor electricity consumption calculation.

7.7.2 SINGLE STAGE EQUIVALENT BURNER OPERATING HOURS

The Department calculated equivalent single-stage burner operating hours as;

$$BOH_{SS} = HHL \times \frac{1000000}{\left[Q_{IN} \times AFUE \times 1000 + 3.412 \times BE \times y \times PE_{IG} \times y_{IG} \times R\right]}$$

where:

HHL	=	the annual household heating load (kBtu/yr),
BE	=	blower motor electrical power consumption,
y	=	ratio of blower on-time to average burner ontime, as defined in the ASHRAE test procedure,[1]
PE_{IG}	=	electrical input rate to the interrupted ignition device on burner,
y_{IG}	=	ratio of ignition device on-time to average burner ontime, as defined in 10.2.1 of DOE test procedure,[2]
R	=	2.3 for two-stage modulation, 3.0 for step-modulating controls when the ratio of minimum-to-maximum output is less than 0.5. (For non-weatherized gas furnaces, the ratio of minimum-to-maximum output is 40% for step-modulating, indicating R = 3.0.), and
$AFUE$	=	Annual Fuel Utilization Efficiency.

For non-weatherized gas furnaces, with electronic ignition, AFUE is the same as steady-state efficiency. This equation for BOH_{SS} is similar to the equation from the DOE test procedure. The main difference is that the LCC spreadsheet has a house heating load for each house, while the test procedure equation uses average heating load hours and design heating requirement (DHR).

7.7.2.1 Annual Average Heating Energy (E_M)

For furnaces and boilers equipped with two-stage or step-modulating controls, the average annual energy used during the heating season, E_M, from ASHRAE Standard 103, is defined as:

$$E_M = (Q_{IN} - Q_P) \times BOH_{SS} + (8760 - 4600) \times Q_P$$

where:

Q_{IN} = steady-state nameplate maximum fuel input rate,
BOH_{SS} = national average number of burner operating hours, and
Q_P = fuel input from pilot light.

For non-weatherized gas furnaces, there is no pilot light, so $Q_P = 0$, and E_M becomes:

$$E_M = Q_{IN} \times BOH_{SS}$$

7.7.3 BURNER OPERATING HOURS AT REDUCED AND HIGH FIRING MODES

The Department calculated burner operating hours (*BOH*) as shown below for reduced firing (R) and high firing (H).

$$BOH_R = \frac{X_R \times E_M}{Q_{IN,R}}$$

where:

X_R = fraction of heating load at reduced fuel input rate operating mode,
E_M = average annual energy used during the heating season (kBtu), and
$Q_{IN,R}$ = steady-state reduced fuel input rate (kBtu/h).

$$BOH_H = \frac{X_H \times E_M}{Q_{IN}}$$

where:

X_H = fraction of heating load at high, or maximum, fuel input rate operating mode, and

Q_{IN} = steady-state high, or maximum, fuel input rate (kBtu/h).

7.7.3.1 Fraction of Heating Load

The Department determined X_H and X_R, the fraction of heating load at the maximum and reduced fuel input operating modes, from a correlation with the balance-point temperature according to ASHRAE Standard 103. Figure 7.7.3.1 shows this correlation.

7.7.3.2 Balance-Point Temperature (T_C)

The balance-point temperature (T_C) apportions the annual heating load between the reduced cycling mode and maximum cycle mode. The Department calculated the balance-point temperature as:

$$T_C = 65 - \left[(60) \times (1 - a) \times \frac{QOUT, R}{QOUT} \right]$$

where:

65 = typical average outdoor temperature at which a furnace or boiler starts operating (°F),

60 = the difference between 65˚F and the typical outdoor design temperature of 5 ˚F (°F),

α = oversize factor,

$Q_{OUT,R}$ = heating capacity at reduced fuel input rate (kBtu/h), and

Q_{OUT} = heating capacity at maximum fuel input rate (kBtu/h).

If the balance point temperature is less than zero, the Department used $T_C = 0$.

7.7.3.3 Oversize Factor (α)

The oversize factor, α, is a ratio between the heating capacity at the maximum fuel input rate and the DHR, less 1, as defined in ASHRAE Standard 103.

$$a = \frac{Q_{OUT}}{DHR} - 1$$

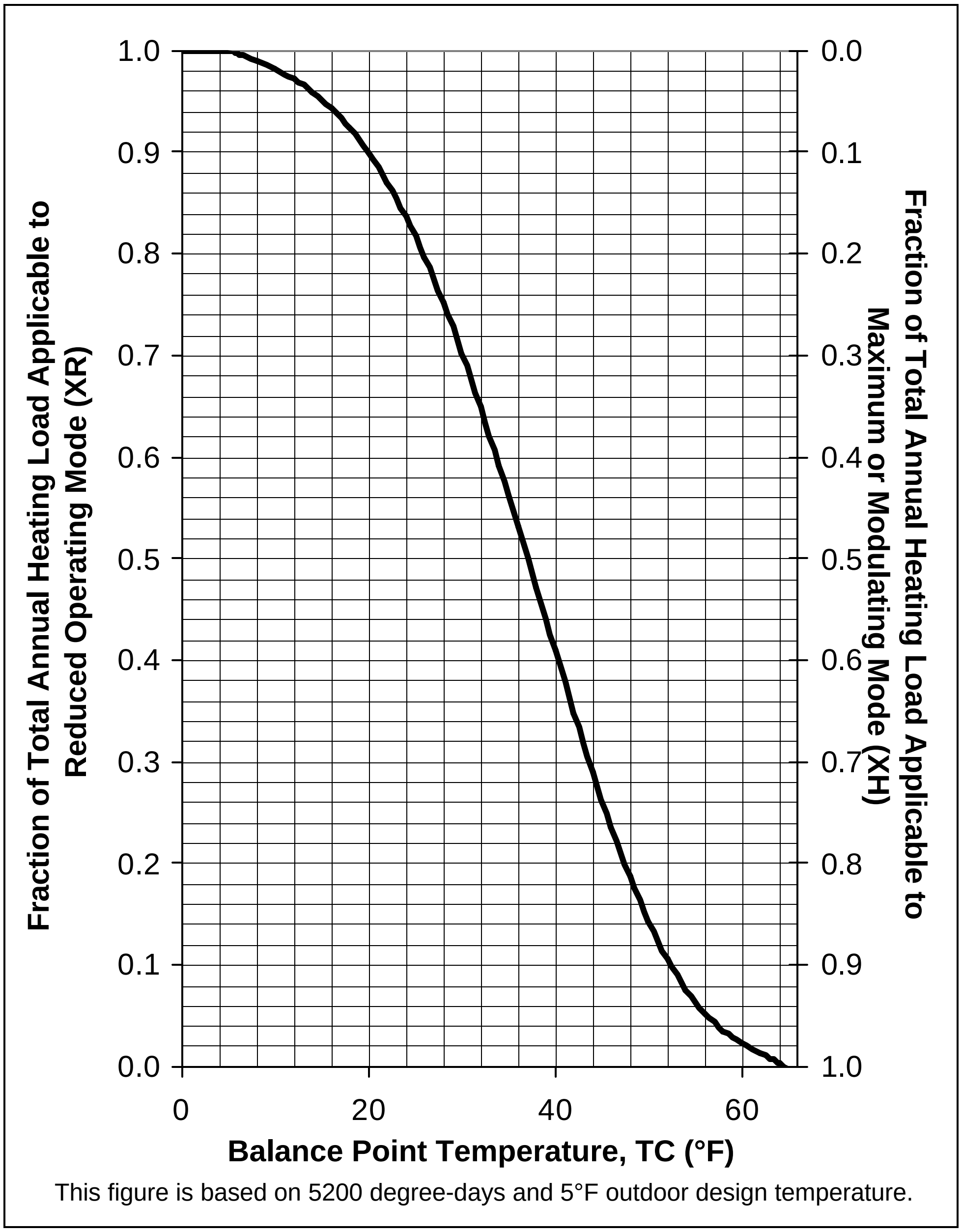

Figure 7.7.3.1 X_R and X_H versus Balance-Point Temperature for Modulating Furnaces and Boilers

7.7.3.4 Heating Capacity at Maximum Input Rate (Q_{OUT})

The Q_{OUT} is expressed to the nearest 1000 Btu/h and is calculated for non-condensing and condensing furnaces as:

$$Q_{OUT} = \quad Q_{IN} \times (0.7247 \times AFUE + 22.346) \text{ for non-condensing and}$$

$$Q_{OUT} = \quad Q_{IN} \times (0.7247 \times AFUE + 22.346) \text{ for condensing furnaces.}$$

The Department derived these equations by fitting a linear function of input capacity and AFUE to the heating capacity of the furnace models listed in the GAMA directory.

7.7.3.5 Reduced Fuel Input Rate Heating Capacity

For $Q_{OUT,R}$, the Department assumed that the steady-state efficiency at the reduced input rate is the same as a maximum input rate. Thus, the reduced fuel input heating capacity is:

$$Q_{OUT,R} = Q_{IN,R} \times \frac{Q_{OUT}}{Q_{IN}}$$

7.7.3.6 Design Heating Requirement

Table 7.7.3.1, taken from ASHRAE Standard 103, shows DHR for boilers and furnaces with different output capacities.

Table 7.7.3.1 Q_{OUT} and Corresponding DHR values

Output Capacity (Btu/h)	DHR (kBtu/h)
5000 - 10,000	5
11,000 - 16,000	10
17,000 - 25,000	15
26,000 - 42,000	20
43,000 - 59,000	30
60,000 - 76,000	40
77,000 - 93,000	50
94,000 - 110,000	60
111,000 - 127,000	70
127,000 - 144,000	80
145,000 - 161,000	90
162,000 - 178,000	100
179,000 - 195,000	110
196,000 and over	130

The Department used the following piece-wise linear equation to determine DHR in the LCC analysis. This avoids discontinuities of DHR as Qout changes bins.

$$DHR = \begin{cases} if\ (Qout < 15) = 0.775 \times Qout - 0.375 \\ if\ (Qout < 30) = 0.5667 \times Qout - 3.25 \\ if\ (Qout \leq 195) = 0.5879 \times Qout - 0.1364 \\ else = 130 \end{cases}$$

For induced draft units,

$$A = \frac{100000}{341300 \times (y_{IG} \times PE_{IG} + y \times BE) \times R + (Q_{IN} - Q_{P}) \times Effy_{HS}}$$

7.7.4 FAN MOTOR ELECTRICITY CONSUMPTION

In modulating furnaces, the circulating blower motor operates at two different rates. At the high firing rate, the blower motor speed is equal to the non-modulating blower speed. At reduced firing rate, the blower motor operates at the lowest speed. The fan motor electricity consumption (BE) for these operating modes is determined as explained in Chapter 7. The burner and the fan motor are coordinated so that when the burner is operating at a particular rate, the blower motor operates at the appropriate speed. Total electricity use is calculated by multiplying the BE at high firing rate times the BOH_H and the BE at reduced firing rate times the BOH_R and summing to get total winter blower electricity consumption.

REFERENCES

1. American Society for Heating Refrigeration and Air-Conditioning Engineers, *Method of Testing for Annual Fuel Ultilization Efficiency of Residential Central Furnaces and Boilers*, 1993, ANSI/ASHRAE. Atlanta, GA. Report No. Standard 103-1993.

2. *Title 10, Code of Federal Regulations, Chapter II Part 430 Appendix N, Subpart B-Uniform Test Method for Measuring the Energy Consumption of Furnaces,* January 1, 2001.